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Interim Report

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SATELLITE DETECTION OF VEGETATIVE DAMAGE AND ALTERATION CAUSED BY
POLLUTANTS EMITTED BY A ZINC SMELTER

E. L. Fritz and S. P. Pennypacker

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INTERDISCIPLINARY APPLICATION AND INTERPRETATION OF ERTS DATA
WITHIN THE SUSQUEHANNA RIVER BASIN

Resource Inventory, Land Use, and Pollution

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THE USE OF SATELLITE DATA
TO DETECT DAMAGED AND ALTERED PLANT COMMUNITIES
CAUSED BY POLLUTANTS EMITTED BY A ZINC SMELTER¹

E. L. Fritz and S. P. Pennypacker

INTRODUCTION

Remote sensing devices have been used to successfully detect such disease problems as late blight of potato (12), maize dwarf mosaic virus (2), oak wilt (14), Dutch elm (14), and root pathogens on citrus trees (17). Insect problems have also been detected and evaluated successfully (5,19). Damage to ponderosa pines caused by air pollutants in the mountains surrounding Los Angeles has been detected and evaluated using large scale aerial photographs (9). Using this detection system and a three stage probability sampling system, a survey was conducted over the San Bernardino National Forest. It was estimated that 1.3 million trees were affected by the pollutants in an area covering 40,400 ha (20).

The recent development of multispectral scanners capable of sensing many spectral energies and recording them simultaneously on magnetic tape has led to a new method of data analysis. The bottleneck of information extraction, the photointerpreter, is bypassed and machine analysis provides a rapid quantitative interpretation of spectral data. The Earth Resources Technology Satellite (ERTS-1) was created, placing a multispectral scanner on a vibration-free space platform. The data collected by ERTS (LANDSAT)-1 are already used in the areas of inventory and management of the earth's resources (11,15), environmental problems (1,3,21), and the control of insect problems (6,8). There have been numerous uses for ERTS-1 data in the fields of geology, oceanography, and photogrammetry.

Pollution is a by-product of the utilization of the earth's resources. In some cases this by-product can damage or inhibit the production of renewable resources such as forest or agronomic crops. The purpose of this study was to determine if ERTS-1 data could be used to detect vegetative damage and altered plant communities resulting from pollutants emitted by a zinc smelter.

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METHODS AND MATERIALS

Sensor System

ERTS-1 was launched in July, 1972, and is now in a polar, sun synchronous orbit 900 km above the surface of the earth. It passes over the same ground area every 18 days. The main functional sensor system on board the satellite is a multispectral scanner (MSS). The MSS divides reflected energy from the earth into four wavelength bands, or channels, by utilizing a prism. The four bands are 0.50-0.60, 0.60-0.70, 0.70-0.80, and 0.80-1.10 μm . A photoelectric sensor converts the energy into electronic signals which are transmitted to receiving stations on the earth. The data are then converted from analog to digital form and stored on magnetic tapes (7). Data are also converted into negative and positive transparencies, approximately 23 x 23 cm in size. The digital and transparency data were made available to investigators through the Goddard Space Flight Center, Greenbelt, MD.

Site

The test area was near Palmerton, Pennsylvania, the site of a zinc smelter since 1898 (18). The roasting of zinc sulphide ores began in 1915, and since then oxides of zinc, lead, cadmium, copper, and sulfur have been released during the roasting and sintering process. Stack tests in 1970 by the Pennsylvania Department of Health measured a total sulfur dioxide emission rate of 635 to 681 kg/h or 15.4 tonnes a day (4). The daily zinc emissions ranged between 6.3 and 9 tonnes. Within a 0.8 km radius of the smelter, zinc concentrations of up to 80,000 $\mu\text{g}/\text{ml}$ of air dried soil occurred in the surface layer of the soil (4).

The town and smelter are in a narrow valley (altitude 152 m) bounded on the south by Blue Mountain (altitude 457 m) and on the north by Stony Ridge (altitude 274 m). The winds in the Palmerton valley are variable, but generally range from north to west. Periods of low wind speed and stagnant air during the early morning hours can occur any time of the year, but are most frequent during the summer (16). During these times pollutants are trapped in the narrow valley (Figure 1).

Vegetation

As a result of logging and burning, the forests surrounding Palmerton are all second growth. Approximately 468 ha of bare soil may be attributed to accumulations of high levels of zinc (4). Large acreages of altered plant communities exist because of sulfur dioxide pollution and zinc in the soil. Areas adjacent to bare soil sites support very little plant life. The only plant in relative abundance is the winter annual Arenaria patula Michx. In other areas the only trees present are sassafras (Sassafras albidum Nutt.) and black gum (Nyssa sylvatica Marsh.) with widely scattered scrub oak (Quercus ilicifolia Wangenh. and Quercus prinus L.). The trees are stunted and there is very little undergrowth (Figure 2). At a distance beyond 0.8 km from the smelter, the forest exhibits a somewhat more normal appearance, although the stands of oak are thinner, the trees possess smaller leaves, and there is less undergrowth.



Figure 1: View of the smelter from Stony Ridge. In the early morning, when wind speed is very low, haze is often present and the odor of sulfur dioxide is distinct.

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Figure 2: A sassafras-oak-black gum area, showing the characteristic lack of undergrowth.

A 4.86 ha white pine (*Pinus strobus* L.) stand situated approximately 1.6 km northeast of the smelter is in a serious state of decline. Most of the trees possess only the current year's and one-year-old needles, both averaging 46 mm in length. At the time satellite coverage was obtained (July 8, 1973), the one-year-old needles displayed tip necrosis and chlorotic mottle. The current year's needles displayed a chlorotic mottle along the entire length of the needle.

A 3.64 ha white pine stand located 2.73 km northeast of the smelter appeared to possess normal or healthy foliage. The trees possessed the current year's needles, one-year-old needles, and two-year-old needles, all averaging 72 mm in length. The average needle length for white pine in the eastern United States is between 60 and 140 mm (11). There was no apparent necrosis or chlorosis present on the needles.

Data Analysis

The main hardware used for automatic processing of the digital tapes was the IBM System 370, Model 168, located at The Pennsylvania State University's Computation Center. Line maps were drawn by a computerized system utilizing a CalComp 564 plotter, and a program called LMAP.

The system used to process MSS data stored on tapes has been described by McMurtry, et al. (13). All programs are stored in library files. The user prepares control specifications for each program in the system; the program accepts the control specifications, processes the ERTS-1 data according to those specifications, and presents the results.

The first program utilized was NMAP, which produces a brightness map. Symbol patterns on this map were used to delineate areas of interest previously chosen. The next program in the system, UMAP, delineates areas possessing uniform spectral signatures. Spectral signatures for uniform areas were obtained by placing their coordinates into the STAIRS program. The spectral signatures were then placed into a classification program to produce a character map similar to that shown in Figure 3. The classification program DCLASS is a euclidean distance classifier which treats each data element point as a point in four dimensional space. Each data point is assigned to that category for which the euclidean distance from the data point to the class mean is smallest, as long as the distance is less than a critical value supplied by the user as part of the input into the program.

If areas of interest are small or non-uniform, they cannot be used in the STAIRS program to obtain spectral signatures. The DCLUS program uses a cluster analysis technique to scan a whole set of data and place points with similar spectral signatures into clusters or groups. This program was used to obtain most of the signatures shown in the map in Figure 3.

The MERGE program allows the user to merge ERTS-1 data from two to six scenes of the same area. The merged data set can then be used in any of the other programs in the system.

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Figure 3: Character map delineating areas of altered or damaged vegetation.

KEY

- @ healthy forest
- *,/ nearly healthy and normal forest
- + sassafrass, black gum, and oak tree area
- bare soil and areas of limited vegetation
- P smelter site
- # waste pile of spent ore and coal

Data Input

ERTS-1 scene number 1350-15190 from July 8, 1973, was the main input for analyzing the Palmerton site. Transparencies of the scene contained no visible cloud coverage. Winter coverage of the test site was also analyzed (scene number 1116-15192, 16 November 1972).

The tape used for the map in Figure 3, employing the signatures in Table 1, covers an area of 100 x 25 nautical miles and contains 1,881,360 data points. By dividing the number of data points into the area covered, it was determined that each data point represents approximately 0.456 ha. This calculated value was used to determine the total amount of area contained in each of the categories in Table 2. The number of data points for each category was provided as part of the output from the classification program. By multiplying the count for each category by 0.456 ha, the associated area was obtained.

Aircraft photographs were used to aid in the verification of the accuracy of the maps produced from the ERTS-1 data. Color positive and color infrared photographs, at a scale of 1:8000, were obtained from low flying aircraft. The coverage did not include the entire test site, however. Photo-revised 7-1/2 minute topographic maps produced by the United States Geological Survey in 1973 were also used as ground truth support.

RESULTS

A cluster analysis of the forested area on the mountain ridge south of the zinc smelter initially revealed that it could be divided into three distinct types. These were ascertained by field trips to the area and by viewing aerial photographs which included portions of each type. The first and most abundant type was noted to be healthy forest. The second type was very similar to the first except that it was thinner and possessed less undergrowth. The third contained mostly sassafras and black gum trees with a few scattered oaks. In this area trees were widely separated and there was no undergrowth; due to lack of vegetation and steepness of the slopes, erosion has taken place in some portions. In addition to these areas, a fourth distinct area was discovered close to the smelter itself. This was an area where zinc concentrations were so high that the soil supported practically no plant life. The only vascular plant species found in abundance was Arenaria patula. Much of the soil is completely barren of plant life and severe erosion has occurred in some sections.

Ground truth revealed very striking differences between the two white pine stands. However, the differences could not be discerned using the ERTS-1 data. Elimination of possible interference from herbaceous undergrowth and deciduous trees, obtained by use of a winter scene, still did not provide spectral signatures capable of recognizing the differences between the two stands. A cluster analysis of the two white pine stands invariably produced nearly identical signatures for both stands. When the winter scene data and the summer scene data were merged, and a cluster

Table 1: Data used to produce the classification map. Categories symbols, limits or critical values, and a set of signatures for each of the four wavelength bands are shown.

No.	Name	Symbol	Limit	Wavelength Band (μm)			
				.5-.6	.6-.7	.7-.8	.8-1.1
Signatures							
1	Healthy forest	@	10.0	38.27	26.55	56.53	30.89
2	Healthy forest	@	10.0	38.15	28.92	50.15	25.28
3	Healthy forest	@	10.0	35.66	23.90	54.49	29.37
4	Healthy forest	@	10.0	44.40	40.20	52.10	24.00
5	Mild decline	*	10.0	34.03	23.08	46.03	24.59
6	Mild decline	*	10.0	26.54	26.00	48.96	25.22
7	Medium decline	+	10.0	36.48	25.83	43.19	21.29
8	Medium decline	+	10.0	35.37	25.65	40.78	20.00
9	Severe decline	.	10.0	39.09	31.26	34.05	13.97
10	Severe decline	.	10.0	39.09	30.84	30.55	11.66
11	Waste pile	#	10.0	36.29	27.73	25.81	9.21
12	Thin forest	/	10.0	37.36	28.60	42.22	20.75
13	Palmerton		10.0	39.35	33.03	40.26	17.65
14	Palmerton		10.0	40.32	34.12	38.43	16.31
15	Palmerton		10.0	41.70	35.04	44.71	19.86
16	Fields	-	10.0	42.25	33.45	55.25	27.92
17	Fields	-	10.0	42.69	34.19	51.51	25.34
18	Highway		10.0	38.44	29.73	41.83	19.67
19	Urban		10.0	38.50	29.73	47.37	23.68
20	Smelter	P	10.0	41.87	36.25	33.15	12.26

Table 2: Categories and symbols used to produce the classification map. The last three columns represent the count or number of data points in each category, the percentage of the total number of data points included in each category, and the total ground area contained by each category.

No.	Name	Symbol	Count	Per Cent	Area (ha)
1	Healthy forest	@	66.	2.	30.1
2	Healthy forest	@	37.	1.	16.8
3	Healthy forest	@	787.	26.	359.0
4	Healthy forest	@	19.	1.	8.6
5	Mild decline	*	202.	7.	92.1
6	Mild decline	*	111.	4.	50.6
7	Medium decline	+	131.	4.	59.7
8	Medium decline	+	363.	12.	165.6
9	Severe decline	.	306.	10.	139.5
10	Severe decline	.	304.	10.	138.6
11	Waste Pile	#	191.	6.	87.1
12	Thin forest	/	67.	2.	30.5
13	Palmerton		71.	2.	32.4
14	Palmerton		65.	2.	29.6
15	Palmerton		94.	3.	42.8
16	Fields	-	6.	0.	2.7
17	Fields	-	13.	0.	5.9
18	Highway		75.	2.	34.2
19	Urban		62.	2.	28.2
20	Smelter	P	75.	2.	34.2
	Unclassified		8.	0.	3.6

analysis performed on the merged data set, again no differences were apparent. Therefore, the sulfur dioxide injury that had occurred to the white pine trees could not be detected.

Table 1 contains the spectral signatures used to produce the map in Figure 3. The signatures for healthy forest, waste pile, and Palmerton were obtained by defining uniform areas of known ground truth from the UMAP output and placing their coordinates into the STATS program. This initial set of signatures was used to produce trial maps of the Palmerton area. Areas on the trial maps which were unclassified were investigated and by the use of the DCLUS program signatures for the unclassified areas were accumulated.

Although various critical distances between 5.0 and 10.0 were used to produce the classification maps, the value of 10.0 produced the most adequate map and was used to produce the map in Figure 3. In the classification scheme, an element was assigned to the category for which the euclidean distance from the element to the category signature was smallest if the distance was smaller than the specific critical distance. If the distance from the element to all categories was greater than the critical distance, the element was unclassified.

The graph in Figure 4 indicates that in the near infrared wavelength bands, 0.70-0.80 and 0.80-1.10 μm , the relative reflectance of electromagnetic energy decreased as the amount of vegetation decreased. This pattern was expected, because healthy vegetation is highly reflective in the near infrared portion of the electromagnetic spectrum while bare soil areas are relatively unreflective. The decline in reflectance in the wavelength bands 0.70-0.80 and 0.80-1.10 μm , displayed by the first 11 signatures in Table 1, was an indication that the signatures were correct. The healthy forest areas contained the most vegetation, while mild, medium, and severe decline areas contained successively less vegetative growth. The waste pile of spent zinc ore and coal contained no vegetation.

The classification map in Figure 3 includes these categories: The small area denoted by the character "P" is the smelter site. The area denoted by the character "#" is a waste pile, approximately 1.93 km in length, of spent zinc ore and coal. The areas adjacent to the waste pile denoted by the character "." are bare soil and sparsely vegetated areas. The areas denoted by the character "+" contain sassafrass, black gum, and oak tree species. The areas denoted by the characters "*" and "/" are nearly normal hardwood forests; the only difference between the two areas is the color of the soil surface showing through the canopy. The area adjacent to these areas, denoted by the character "@", is the healthy forest. The blank areas, having no characters, were not mapped by the program because characters were not assigned to their spectral signatures. These areas, containing roads, lawns, houses, and gardens, were left blank because too many symbols caused the map to be unreadable. This synoptic view of the Palmerton site displays a distinct gradient of less damage and alteration caused by accumulations of zinc in the soil as the distance from the smelter increases.

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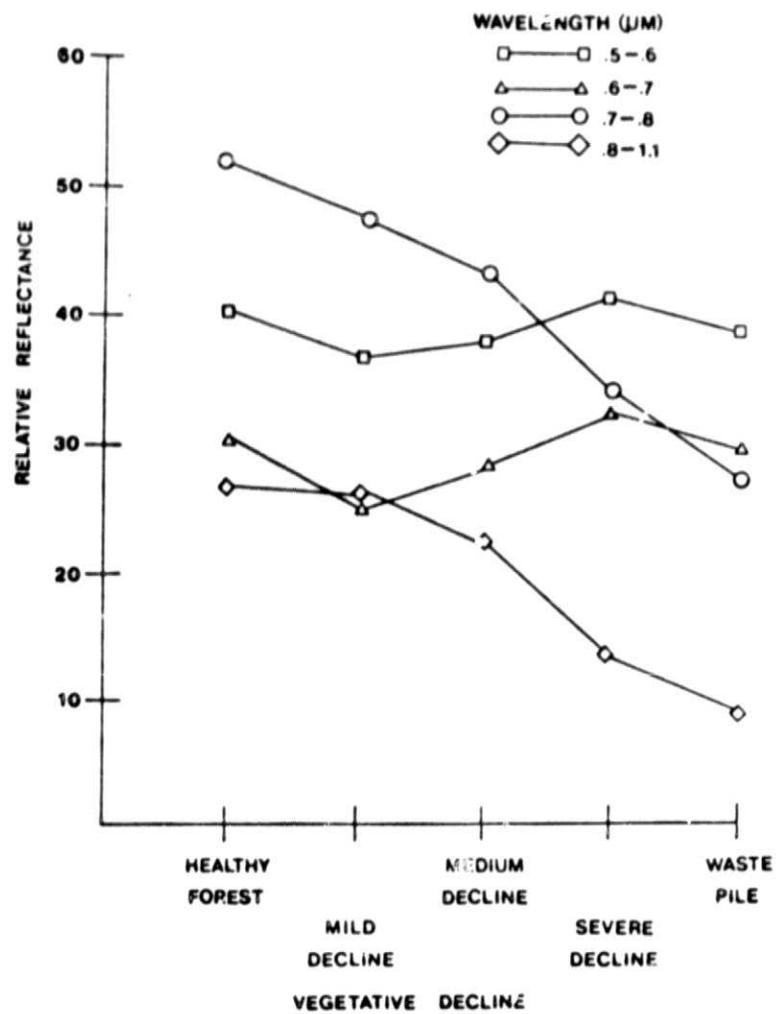


Figure 4: Relative reflectance versus vegetative decline. The figures used are from Table 2. Values for all classes except the waste pile are means.

A problem arose that caused some difficulty in the production of the original classification map in Figure 3. A large shadow present on the north slope of the mountain ridge, caused by the steepness of the slope, covered portions of the altered areas and healthy forest. This shadow caused areas of similar ground truth to produce two different spectral signatures with the ERTS-1 data, and therefore the areas appeared different on maps produced by the cluster analysis procedure. To produce a more accurate classification map, both signatures were assigned the same character. For instance, portions of the healthy forest in shadowed and non-shadowed areas produced different spectral signatures: signatures 2 and 4 in Table 2 are healthy forest signatures for shadowed areas and signatures 1 and 3 are healthy forest signatures for non-shadowed areas. The shadow effect was eliminated from the final map (Figure 3) by assigning the same character, "@", to both signatures in the classification program.

The line map in Figure 5 has been plotted from the digital map using the LMAP program. This program corrects line and element distortion which is inherent in the digital data output.

DISCUSSION

The results show both the usefulness and weakness of the ERTS-1 remote sensing capabilities. The data produced a map accurately delineating areas surrounding a zinc smelter which may be limited in vegetative production due to the zinc emitted by the smelter. Herein lies the strength of the ERTS-1 system. The management of resources usually involves a three-step process of inventory, analysis, and allotment. This study has demonstrated the tremendous usefulness of the capability of the ERTS-1 system in inventorying present and potential resources. It provides synoptic views of the earth's resources that include a temporal factor, because the satellite passes over the same area every 18 days.

The ERTS-1 data, however, do not appear useful for evaluating the condition of vegetation, especially small acreages of damage similar to that investigated herein. Air pollution damage is often restricted to small acreages of scattered susceptible plants. The differences in spectral signatures from such damaged and healthy foliage are not large enough to be detected by the ERTS-1 remote sensing systems. The ERTS-1 system would be useful only on occasions when large areas of damage occur and the damage is severe enough to use a high contrast between damaged and healthy vegetation. Even in such cases, the resolution of the system will not allow an adequate evaluation of the amount of damage that had occurred to the plants.

In the future, an ERTS-1 type satellite may effectively be used as a detection system capable of inventory but not particularly useful in evaluation.

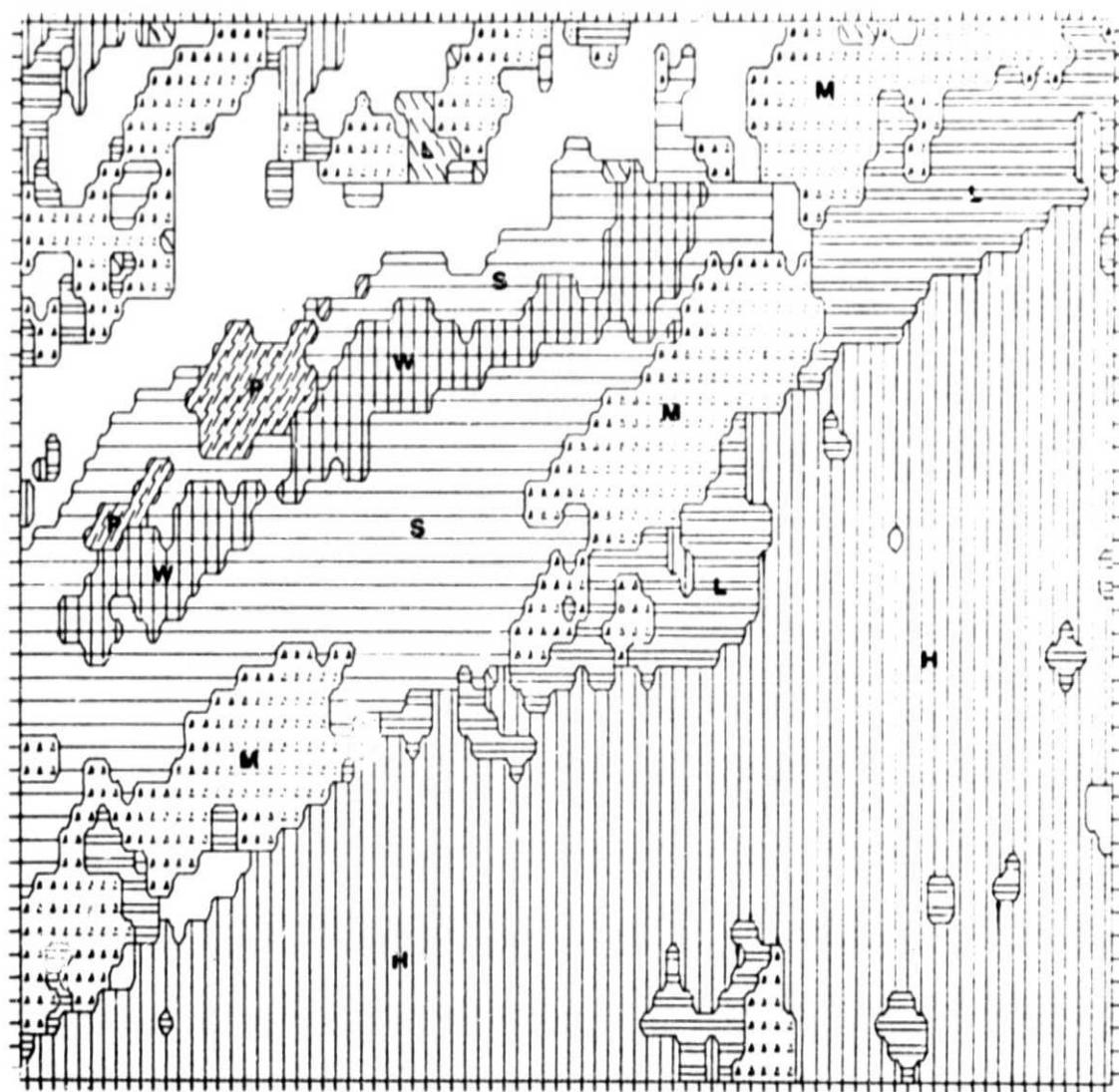


Figure 5: Line map produced by the CalComp 564 plotter, using the digital map in Figure 3 as input.

KEY

- E healthy forest
- L mild decline
- M medium decline
- S severe decline
- P smelter site
- W waste pile

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ABSTRACT

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SATELLITE DETECTION OF VEGETATIVE DAMAGE AND ALTERATION CAUSED BY
POLLUTANTS EMITTED BY A ZINC SMELTER
E. L. Fritz and S. P. Pennypacker

Data collected by a multispectral scanner on board the Earth Resources Technology Satellite (ERTS-1) were subjected to computer analysis in an attempt to detect vegetative damage and alterations caused by pollutants emitted from a zinc smelter. Field observations and data collected by low flying aircraft were used to verify the accuracy of maps produced from the satellite data. Although areas of vegetation as small as six acres can accurately be detected, a white pine stand that was severely damaged by sulfur dioxide could not be differentiated from a healthy white pine stand because spectral differences were not large enough. When winter data were used to eliminate interference from herbaceous and deciduous vegetation, the damage was still undetectable. The analysis was able to produce a character map that accurately delineated areas of vegetative alteration due to high zinc levels accumulating in the soil. The map depicted a distinct gradient of less damage and alteration as the distance from the smelter increased. Although the satellite data will probably not be useful for detecting small acreages of damaged vegetation, it is concluded that the data may be very useful as an inventory tool to detect and delineate large vegetative areas possessing differing spectral signatures.